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A PROCEDURE TO DETERMINE IF MINE SPOILS
WILL REACH A DOWNSLOPE STREAM CHANNEL

DEVELOPED BY

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MARCH 1982

WATERSHED SYSTEMS DEVELOPMENT GROUP
USDA FOREST SERVICE
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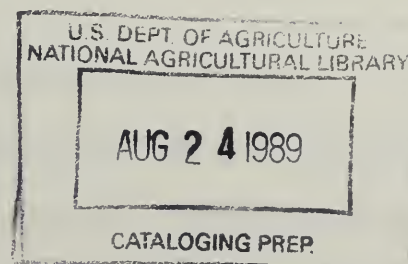
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1.0 Introduction

When evaluating proposed shaft mine operating plans, a field forester may on occasion desire to determine if mine tailings will reach downslope stream channels. This information would be very useful in the evaluation effort but is, by and large, unavailable. The problem, movement of mine spoils, entails the consideration of several variables related to terrain and spoils materials. Such a consideration quickly becomes complex and very site specific.

The following is a simplified approach to the problem and yields an estimate of either allowable spoils volume or critical slope distance. The procedure may be employed by the field forester to determine, at the outset, the need for mitigative measures.

It must be made clear that this procedure is not to be employed without professional discretion. Variations in slope form, e.g., convex vs. concave, and roughness must be taken into account by the field forester when evaluating operating plans. This simplified procedure does not account for these variables. Thus, the forester's professional estimate of impact may run counter to the results derived from the procedure. Such a determination may be quite valid when viewed in light of the "confounding" variables of slope form, etc., which are not treated.

2.0 Procedure

2.1 Conceptual

The procedure presented here is simply an application of basic geometry. What is calculated is a portion of the volume of a frustum of a right circular cone and a triangular prism. In essence, I have taken the cone produced by dumping spoils out of a mine shaft and subtracted the

hillside volume to estimate the volume available for spoils. All that is required for this determination is the angle of the hillside, the angle of repose for the spoils, and how far downslope it is to the channel of concern. If the volume available for the spoils is not large enough, then we can determine how far along the slope (parallel to the contour) the pile would have to extend to prevent material from reaching the channel.

Consequently, the field forester can use this procedure when evaluating a miner's operating plan and determine whether or not to request cribbing, moving spoils to other sites, or other appropriate mitigative measures if it appears the spoils will enter the stream channel.

Figure 1 represents a triangular prism, a right circular cone, and a frustum of a right circular cone, with R_1 and R_2 describing radii as indicated: D, diameter; L, length; h, height; A, B, C, angles; and a, b, c, sides of a triangle.

These figures are described by the following formulas:

Volume of circular cone:

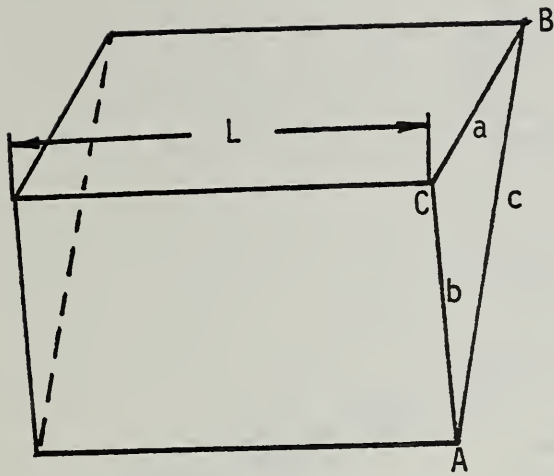
$$V_C = \frac{\pi D^2 h}{12} \text{ or } V_C = \frac{\pi R_1^2 h}{3} \quad [1]$$

Volume of frustum of right circular cone:

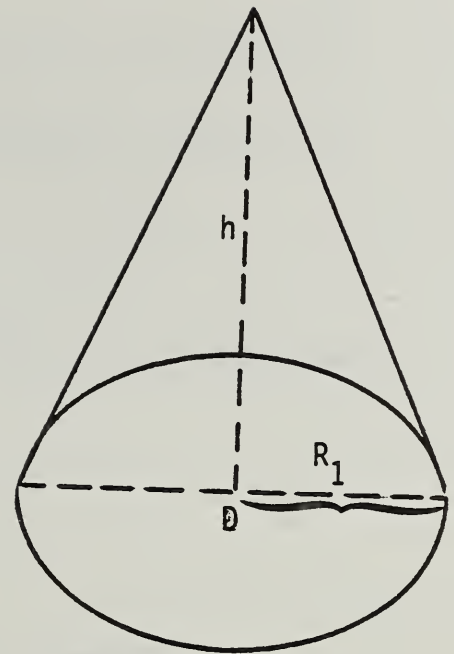
$$V_F = 1/3\pi h(R_1^2 + R_2^2 + R_1 R_2) \quad [2]$$

Volume of a triangular prism:

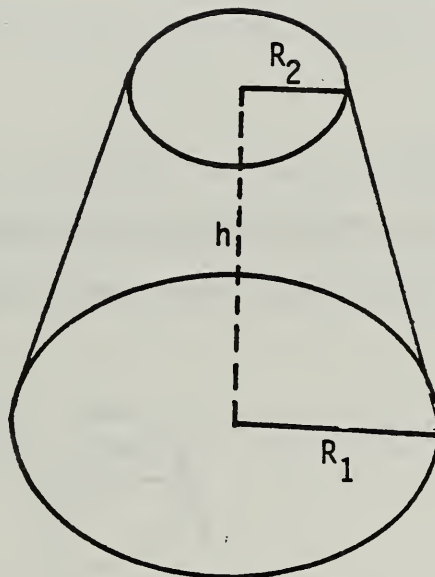
$$V_P = \frac{c^2 \sin A \sin B}{2 \sin C} \times L \quad [3]$$



Triangular Prism



Circular Cone



Frustum of a Right Circular Cone

Figure 1. Geometric Shapes.

In this procedure, the hillside is considered to be half of a right circular cone as illustrated in Figure 2 and equation [4].

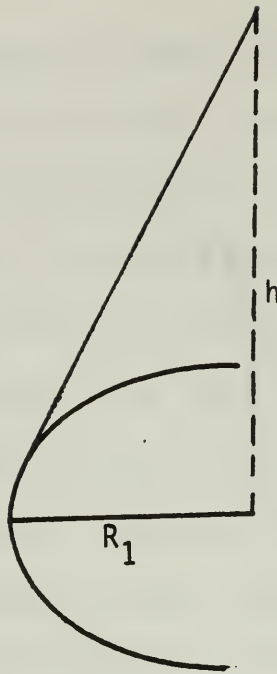


Figure 2. Portion (1/2) of Right Circular Cone.

Volume of hillside:

$$V_T = 1/2 V_C \quad [4]$$

Next, if we envision only half of the frustum we begin to see something that looks like a small mine spoils pile:

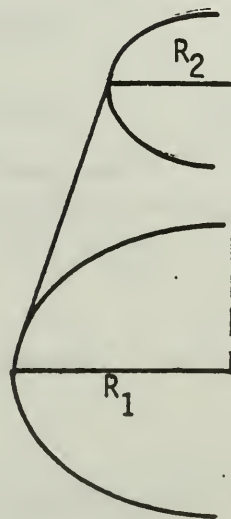


Figure 3. One-half Frustum of Right Circular Cone.

Volume of one-half frustum of right circular cone:

$$V_f = 0.5 V_F \quad [5]$$

Now, if we combine these two figures and display in longitudinal section (along the longer axis) we see, with imagination, a hillside (V_T) with a tailings pile (V_X):

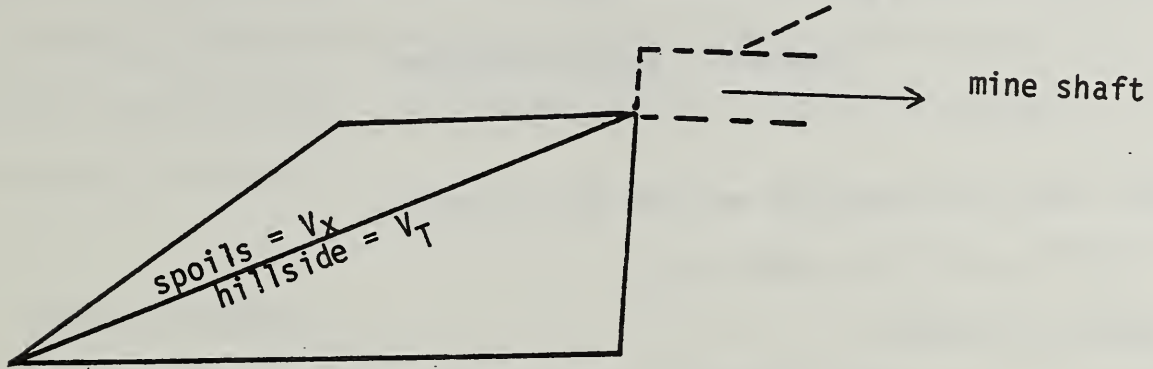


Figure 4. Longitudinal Section of Combined Projections.

It now follows that the volume of the 1/2 frustum (V_T) equals the volume of spoils (V_X) plus the volume of the hillside V_T (1/2 the right circular cone) or:

$$V_f = V_X + V_T \quad [6]$$

Through algebraic manipulation we have the volume of spoils represented by the following:

$$V_X = V_f - V_T \quad [7]$$

Combining terms gives:

$$V_X = 1/2 (1/3\pi h(R_1^2 + R_2^2 + R_1R_2)) - 1/2 (1/3\pi R_1^2 h) \quad [8]$$

which reduces to:

$$V_X = 1/6\pi h(R_2^2 + R_1R_2) \quad [9]$$

Labeling Figure 4 gives us the following:

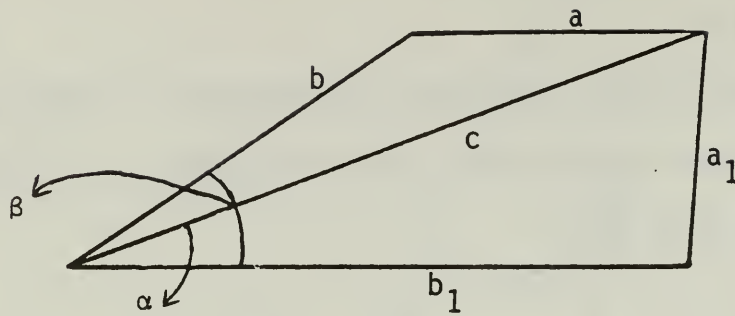


Figure 5. Labeled Section.

Using this labeling convention we have the following:

$$R_1 = b_1; R_2 = a; \text{ and } h = a_1.$$

Thus equation 9 becomes:

$$V_x = 1/6\pi a_1(a^2 + b_1a) \quad [10]$$

From trigonometry, we have the following relations:

$$a_1 = c \sin \alpha; b_1 = c \cos \alpha; \text{ and } a = \frac{c \sin (\beta - \alpha)}{\sin \beta}.$$

We can now arrive at our destination:

$$V_x = 1/6\pi c \sin \alpha \left[\left(\frac{c \sin (\beta - \alpha)}{\sin \beta} \right)^2 + (c \cos \alpha) \frac{c \sin (\beta - \alpha)}{\sin \beta} \right] \quad [11]$$

2.2 Angle of Repose

The angle of repose will be most reflective of local conditons if it is determined by measuring existing spoils piles in the vicinity. This value should be determined for each kind of spoils material likely to be encountered. This will be a function of geologic parent material. It

should also be sensitive to the size and angularity of material as spoiled. Angular rocks with a diameter of three feet will not be likely to have the same angle of repose as rounded gravel or sand.

The angle of repose figures are not difficult to secure. It just requires a level and stadia rod, a number of sites, and a simple analysis of variance (to make sure the means of the different size groups are different statistically). With these things in hand, a reasonable evaluation can be made.

2.3 Data Requirements

The field forester must provide the following data:

1. Slope distance between mine shaft and drainageway. This value may be calculated in the office using topographic maps if corrections are made for the slope steepness. It will be more practical to measure by taping or pacing the distance in the field.

2. Hillslope angle. This value is critical and requires a field visit. It should not be taken from topographic maps. A clinometer or Abney level should be used, at least, and at least three sightings should be taken and averaged to produce a reasonable estimate.

3. Spoils angle of repose. This may be the figure used in this document. However, a set of locally derived values for existing piles will be more representative. These should be separated by size groupings and/or material type and subjected to a simple analysis of variance (generally incorporated in handheld calculators).

The miner must provide the following data:

1. Mine spoils dump location. Best accomplished through a field visit.

2. An estimate of volume of material in tons. This should be a best guess value and not especially conservative.

3. An indication of likely size of material. An indication of whether the material will be boulders or sand, for example, so that the appropriate angle of repose may be selected.

4. An indication of the nature of the majority of the material to be spoiled -- for example, gneiss, granite, quartz, etc.

2.4 Procedural Example

Consider the following example: A miner proposes to spoil approximately 200,000 tons of broken gneiss on a 55 percent slope. The creek of concern is 350 feet downslope. The question is: Will the spoils impact the stream?

Assume:

1. From local data the angle of repose (β) is determined to be 39 degrees (for coarse material), and

2. The slope is uniform and essentially smooth.

Procedure:

1. Determine the volume of 200,000 tons of broken gneiss. Using page 97 of USDI, BLM Field Handbook for Mineral Examiners (see Appendix I), we find that gneiss produces 20.8 cubic feet per ton. Thus, the volume equals

$$V_y = 200,000 \text{ T.} \times 20.8 \text{ ft}^3/\text{T.} = 4,160,000 \text{ ft}^3$$

2. Change percent slope to degrees (i.e., slope angle = \tan^{-1} (percent slope)):

$$55\% = .55, \tan^{-1} .55 = 28.81^\circ, 29^\circ = \alpha.$$

3. Find values for a_1 , b_1 , a , and c :

a) $c = 350$ feet, given

$$\begin{aligned}
 (b) \quad a_1 &= c \sin \alpha \\
 &= (350) \sin 29^\circ \\
 &= (350) (0.485) = 169.68 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 (c) \quad b_1 &= c \cos \alpha \\
 &= (350) \cos 29^\circ \\
 &= (350) (0.875) = 306.12 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 (d) \quad a &= \frac{c \sin (\beta - \alpha)}{\sin \beta} \\
 &= \frac{(350) \sin (39 - 29)}{\sin 39} \\
 &= \frac{(350) \sin 10}{\sin 39} \\
 &= \frac{(350) (0.174)}{0.629} = 96.82 \text{ ft}
 \end{aligned}$$

4. Applying formula 11:

$$\begin{aligned}
 V_x &= 1/6\pi c \sin \alpha \left[\left(\frac{c \sin (\beta - \alpha)}{\sin \beta} \right)^2 + (c \cos \alpha) \frac{c \sin (\beta - \alpha)}{\sin \beta} \right] \\
 &= 1/6\pi 169.68 [(96.82)^2 + (306.12) (96.82)] \\
 &= 1/6\pi 169.68 (9374.11 + 29,638.54) \\
 &= 1/6\pi 169.68 (39012.65) \\
 &= 3,466,049.3
 \end{aligned}$$

5. Compare the answer with the volume proposed in the operating plan:
 approximately 3,470,000 ft³ vs. approximately 4,160,000 ft³

It is evident that the volume of material that would fill the space available, based upon the locations of stream and mine relative to one another, is less than that which will be produced. Mitigative measures are clearly in order.

Appropriate mitigative measures might include cribbing to increase the allowable volume without increasing "c" or we might try increasing the length of the pile along the slope contour. Increasing this length requires the introduction of the triangular prism mentioned earlier.

We can conceive of a spoils pile in this configuration as being formed by the previously calculated frustum split in two with a triangular prism inserted between the two halves, as described below and in Figure 6.

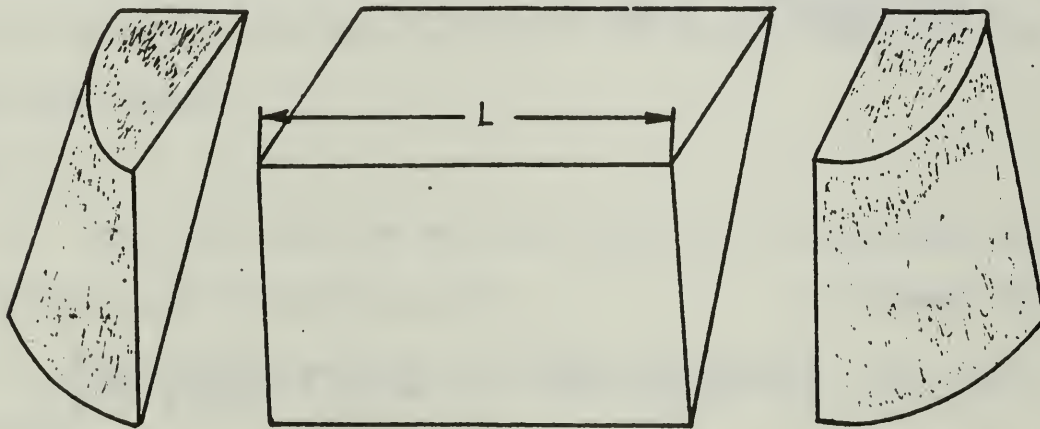


Figure 6. Triangular Prism Inserted Within Frustum.

The volume of the triangular prism (V_p) is given by formula 3.

$$V_p = \frac{c^2 \sin A \sin B}{2 \sin C} \times L$$

If the hillside will allow, the total volume of spoils piled in this fashion can be represented as:

$$V_{TS} = V_X + V_p \quad [12]$$

In our above example, we had a volume in excess of that which could be accommodated without some mitigative measure. This volume is represented as the difference between proposed and allowable, i.e.:

$$V_Y - V_X = \text{Excess} \quad [4]$$

or

$$4,160,000 \text{ ft}^3 - 3,470,000 \text{ ft}^3 = 690,000 \text{ ft}^3$$

The excess volume ($690,000 \text{ ft}^3$) can be accommodated through the piling of material parallel to the contour for approximately 85 feet.

We arrive at this figure through the following:

$$V_p = \frac{c^2 \sin A \sin B}{2 \sin C} \times L$$

and since c is given, $A = \beta - \alpha$, $B = \alpha$,

$$C = 180 - \beta, \text{ and } \sin 180 - \beta = \sin \beta$$

we get the following

$$V_p = \frac{c^2 \sin (\beta - \alpha) \sin \alpha}{2 \sin \beta} \times L$$

Next, letting $V_p = 690,000$ (the excess volume) we have the following:

$$690,000 = \frac{(350)^2 \sin (10^\circ) (\sin 29^\circ)}{2 \sin (39^\circ)} \times L$$

$$690,000 = 8193.62 L$$

Thus:

$$84.21 = L \text{ or, rounding upward, approximately 85 feet.}$$

Thus, we have determined the approximate magnitude of impact of the proposed spoils, at least insofar as their reaching a drainageway is concerned. Furthermore, we have determined the area necessary to hold these spoils if the drainage is to be protected. We also have an idea of the likely visual impact.

Additional calculations can be made by the hydrologist to evaluate potential water quality problems due to leaching, etc. Such, however, are beyond the scope of this procedure.

The alternative solution for slope distance will not be treated here. Clearly, algebraic manipulation and solving for "c" are all that is required.

3.0 Assumptions

Before applying this methodology, the user must be cautioned about the underlying assumptions incorporated in this procedure:

1. The foremost assumption is that spoils can be described as a partial frustum of a right circular cone. This is a reasonable and necessary assumption.

2. Also significant is the approximation of the hillside as a right circular cone with the same radius, at its base, as that of the frustum. This is obviously incorrect. The radius of the cone may be, in fact, very much larger, or occasionally, slightly smaller. In most cases, it will be larger and thus the procedure will overestimate the allowable volume of spoils.

3. No attempt is made, in this procedure, to deal with rolling or tumbling debris. Such may clearly reach a drainageway as a consequence of momentum.

4. Only a uniformly smooth slope is treated; neither convex nor concave slopes are evaluated.

5. The assumption of a flat-topped pile and downhill spoiling may be obvious, but should be noted.

6. Where the triangular prism is employed, additional assumptions include the uniformity of both the hillslope and the spoils pile, i.e., spoils cross sectional area does not change and the hillside is a plane.

7. Another area in which assumptions are made is in the use of any particular spoils angle of repose. My measurements in northern Colorado produced the following figures for spoils angle of repose for gold and silver mines:

coarse textured (39°)*

fine textured (34°)*

Obviously, the more site specific the spoils angle of repose data, the greater will be the confidence in its use. The user is therefore encouraged to secure these data.

All of the above are simplifying assumptions which make a procedure feasible. The user is again cautioned that professional discretion must be used in its application. If the simplifying assumptions are problematic, then the user should either temper the conclusions or discard the methodology. In my view, however, these assumptions are not debilitating in and of themselves.

One final caution: the field forester should not forego any future options for requiring mitigation since the calculations may be found to be

*These two values are significantly different from one another at the 0.975 level with 11 degrees of freedom.

in error, the miner's estimates might be incorrect, or some other unforeseen factors may arise. This procedure merely indicates potentials, and forestalls or eliminates, in some cases, the unnecessary application of expensive mitigative measures. Of course, the procedure also attempts to avoid stream impacts by providing an early indication of potential damage and facilitating the timely application of appropriate mitigative measures.

With these points in mind, the field forester should be able to make a reasonable judgment based upon a reasonable methodology tempered by experience and professional judgment.

4.0 Hydrologist, Soil Scientist or Watershed Specialist Assistance

The foregoing is presented so that the field forester may accomplish the calculations himself with the aid of a handheld calculator. If, however, this is not feasible, the following form is offered to assist in sending required data to the specialist.

Ranger District Beaver Date February 30, 1981
Name of District Person Responsible G.D.A. - Forester
Name of Project Proposal Example - Text
Kind of Project (gold, silver, tin, etc.) Gold
Slope Distance to Nearest Downslope Drainage (in feet) 350 (p. 8)
Nature of Drainage (perennial, ephemeral, intermittent) Perennial
Slope Angle (as %) 55 (p. 8) (or as degrees) _____
Volume of Spoils (in tons) 200,000 (P) (or in cubic feet) _____
Kind of Material (gneiss, granite, etc.) Gneiss (p. 8)
Average Size of Material in Spoils Coarse (6")
Spoils Angle of Repose (if different from forest values) Forest value
Length of Hillside Available for Piling (along the contour) Unlimited

5.0 Programmable Calculator Programs

Two programs for a handheld HP-33C are presented in Appendix II. The first uses β , α and c as input and calculates the allowable volume (V_X) in ft^3 . If this volume is less than the proposed spoils volume (V_Y) the user can then input the proposed volume (V_Y) in ft^3 and the program will calculate the distance, in feet, along the hillside contour (L) required to maintain the critical distance (C).

The second program uses β , α and proposed volume (V_Y) to calculate the downslope distance (C), in feet, required to hold the proposed volume.

APPENDIX I

Table 16.--Weight of rocks**

Material	Wt. per cu. ft., lb.		Cu. ft. per ton		Tons per cu. yd.	
	In place	Broken	In place	Broken	In place	Broken
Dolomite	160	--	12.5	----	2.16	1.30
Gneiss	168	96	11.9	20.8	2.27	1.30
Granite and porphyry	170	97	11.8	20.6	2.30	1.31
Greenstone and trap	187	107	10.7	18.7	2.52	1.39
Hematite*	267	--	7.5	----	3.60	----
Limestone	168	96	11.9	20.8	2.27	1.30
Limestone ores*	154	--	13.0	----	2.08	----
Quartz	165	94	12.1	21.3	2.23	1.27
Quartzose ores*	138	--	14.5	----	1.86	----
Sandstone	151	86	13.2	23.3	2.08	1.16
Slate	173	95	11.4	21.1	2.36	1.28
Vein quartz*	148	--	13.5	----	2.00	----
Vein quartz, 15% PbS*	164	--	12.2	----	2.21	----
Vein quartz, 15% FeS ₂ *	160	--	12.5	----	2.16	----

*Refers to possible wt. of ores: pure minerals usually weigh more.

Swelling in fill.--On excavating a mixture of solid and loose rock and earth, 1 cu. yd. in place makes about 1.4 cu. yd. in fill. If rock be first stripped of earth, and then blasted and dumped by itself, the percentage of voids is larger. At Boulder, Colo., 3,600 cu. yd. of solid rock made a 5,340 cu. yd. embankment: a ratio of 1:1.51. In Virginia, 50,000 cu. yd. of limestone and mica schist, broken and put in embankment, made 90,000 cu. yd. an increase of 80%. In subaqueous excavation.--Ashtabula Harbor, 62,869 cu. yd. (place measure) gave 103,537 cu. yd. measured in scows, an increase of 65%. 18 cubic feet of earth or gravel in place equals approximately 27 cubic feet when excavated.

**USDI, Bureau of Land Management, Field Handbook for Mineral Examiners.

APPENDIX II

PROGRAM FOR CALCULATION OF " V_x " AND "L" USING HP-33C

Program Step	Key	Program Step	Key	Program Step	Key
0	f clear	17	f sin	33	$g\pi$
	pgm	18	RCL 3	34	X
1	STO 1	19	X	35	6
2	R/S	20	STO 5	36	\div
3	STO 2	21	RCL 2	37	R/S
4	R/S	22	f cos	38	$X \geq Y$
5	STO 3	23	RCL 3	39	-
6	RCL 1	24	X	40	STO 7
7	RCL 2	25	STO 6	41	RCL 4
8	-	26	RCL 4	42	RCL 5
9	f sin	27	X	43	X
10	RCL 3	28	RCL 4	44	2
11	X	29	$g \times^2$	45	\div
12	RCL 1	30	+	46	RCL 7
13	f sin	31	RCL 5	47	\div
14	\div	32	X	48	$g \ 1/x$
15	STO 4				
16	RCL 2				

RUNNING THE PROGRAM

Key Strokes	Display	Comments
f fix 0	0	Sets Display to whole numbers.
g rtn	0	Sets Program at beginning.
input (β)	β	Input β - in degrees (eg. 39).
R/S	β	
input (α)	α	Input α - in degrees (eg. 29).
R/S	α	
input (c)	c	Input c - in feet (eg. 350)
R/S	V_x	Allowable volume in ft^3 If less than proposed continue.
input (V_y)	V_y	Input Proposed Spoils Volume - in ft^3 (eg. 4,160,000).
R/S	L	Length along hillside in ft.

PROGRAM FOR CALCULATION OF C USING HP-33C

<u>Program Step</u>	<u>Key</u>	<u>Program Step</u>	<u>Key</u>	<u>Program Step</u>	<u>Key</u>
0	f clear pgm	15	f sin	30	g 1/x
1	STO 1	16	RCL 4	31	6
2	R/S	17	÷	32	X
3	STO 2	18	STO 6	33	gπ
4	R/S	19	RCL 2	34	÷
5	STO 3	20	f cos	35	RCL 5
6	RCL 1	21	RCL 6	36	÷
7	f sin	22	X	37	.
8	STO 4	23	STO 7	38	3
9	RCL 2	24	RCL 6	39	3
10	f sin	25	g x ²	40	3
11	STO 5	26	RCL 7	41	3
12	RCL 1	27	+	42	3
13	RCL 2	28	RCL 3	43	f y ^x
14	-	29	÷		

RUNNING THE PROGRAM

<u>Key Strokes</u>	<u>Display</u>	<u>Comments</u>
f fix 0	0	Sets Display to whole numbers.
g rtn	0	Sets Program at beginning.
input β	β	Input β - in degrees (eg. 39).
R/S	β	
input α	α	Input α - in degrees (eg. 29).
R/S	α	
input V _y	V _y	Input Volume - in ft ³ (eg. 4,160,000).
R/S	c	Critical Distance required - in feet.

APPENDIX III

Ranger District _____ Date _____
Name of District Person Responsible _____
Name of Project Proposal _____
Kind of Project (gold, silver, tin, etc.) _____
Slope Distance to Nearest Downslope Drainage (in feet) _____
Nature of Drainage (perennial, ephemeral, intermittent) _____
Slope Angle (as %) _____ (or as degrees) _____
Volume of Spoils (in tons) _____ (or in cubic feet) _____
Kind of Material (gneiss, granite, etc.) _____
Average Size of Material in Spoils _____
Spoils Angle of Repose (if different from forest values) _____
Length of Hillside Available for Piling (along the contour) _____

Ranger District _____ Date _____
Name of District Person Responsible _____
Name of Project Proposal _____
Kind of Project (gold, silver, tin, etc.) _____
Slope Distance to Nearest Downslope Drainage (in feet) _____
Nature of Drainage (perennial, ephemeral, intermittent) _____
Slope Angle (as %) _____ (or as degrees) _____
Volume of Spoils (in tons) _____ (or in cubic feet) _____
Kind of Material (gneiss, granite, etc.) _____
Average Size of Material in Spoils _____
Spoils Angle of Repose (if different from forest values) _____
Length of Hillside Available for Piling (along the contour) _____

